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## (54) ELECTROPHORETIC DISPLAY DEVICE

(71) We, NORTH AMERICAN PHILIPS CORPORATION, residing at 100 East 42nd Street, New York 10017, New York, United States of America, a Corporation organised and existing under the laws of the State of Delaware, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

This invention relates to an electrophoretic visual display device. Multisegmented electrophoretic image display cell devices or EPID cells are known in the art and are described, for example, in United States Patent 3,792,308 and Ota et al, Proceedings of the IREE Vol. 61, No. 7, July 1973, pages 832-836.

A multisegmented EPID cell of the kind employed in the present invention comprises charged light-reflecting pigment particles suspended in a dark coloured liquid between a front, transparent electrode and a back electrode, patterned into segments, and a field or background electrode.

By applying a D.C. field across the suspension, the particles are moved to one or the other of the electrodes depending upon the polarity of the charged particles.

For example, in the area of negatively charged pigments when the front transparent electrode is at ground potential, the field electrode is positive, the selected segment electrodes are negative and the non-selected segment electrodes are positive, the particles in the area of the selected segment electrodes are repelled to the front transparent electrode while the other particles in the area of the positively charged field and non-selected segment electrodes are attracted to those electrodes. An observer, viewing through the transparent electrode, sees the shape of the selected segmented electrodes due to the deposited layer of light reflecting particles on a dark background, since the dark suspension liquid hides the pigment attracted to the field electrode and the non-selected segment electrodes. By switching the polarity so that the selected electrode segments are positive and the field and non-selected segment electrodes are negative, the position of the pigment is reversed so that the observer now sees the selected electrode segment as a dark image on a light background.

A problem with these EPID devices arises from the fact that lead lines conducting current from the power source to the electrode segments themselves act as electrodes and tend to attract or repel the charged pigment and thus become visible to the observer and detract from the appearance of the desired image.

In order to hide these lead lines, cut-out masks have been placed between the observer and the display or the part of the transparent electrode facing the lead lines have been painted over with an opaque paint.

These methods have not proved very successful, as the difficulty of matching the colour of the mask or paint to the colour of the suspension liquid often detracts from the appearance of the EPID cell, particularly when employed in such a consumer item as a clock.

Another problem is that the use of masks or opaque paints is not possible in those EPID cells where it is desired to reverse the tone of the background and the segmented electrodes by reversing their polarity.

One object of this invention is to reduce unwanted switching caused by the lead lines and thus hide the lead lines in an EPID cell or device from the observer.

Another object of the invention is to provide a method of preparing an electrophoretic visual display device in which the lead lines in the device or cell are hidden

from the observer in a way which is independent of changes in tone between the segmented electrodes and the background.

According to the present invention there is provided an electrophoretic visual display device comprising:

an electrophoretic suspension of an opaque insulating liquid containing charged pigment particles of a contrasting colour to that of said liquid and generally of a single polarity:

a first transparent electrode;

at least one segmented electrode and a field electrode having a major surface in opposite to the major surface of said first transparent electrode and spaced therefrom by at least one thin insulating member;

an insulating layer in contact with the surface of said segment and field electrodes and having electrically conductive channels or vias providing electrically conductive passages from said segmented and field electrodes through said insulating layer;

voltage supply means for supplying a reversible electric field between said first transparent electrodes and said segmented and field electrodes;

electrical lead lines positioned on the surface of said insulating layer remote from said segmented and field electrodes and electrically connected thereto through said electrically conductive channels or vias, and with electricially conductive means electrically connecting said lead lines to said voltage supply means.

The lead lines are separated from the field electrode and segmented electrodes by means of an electrically insulating layer through which there are conductive channels or vias connecting the lead lines to the field or segment electrodes.

On the EPID cell of the invention, the surface of the insulating layer is coated with the field and segment electrodes which are in contact with the suspension, while the lead lines are separated from the suspension by the electrode and insulating layers. By this construction, an electrical field is prevented from being developed between the lead lines and the front transparent electrode.

Thus there is no repelling or attracting of pigment to the transparent electrode due to the lead lines and the lead lines are effectively hidden from the observer.

Further, when the polarity of the segment and field electrodes is reversed, and the tone of the selected segment electrodes and the non-selected segment and background field electrodes is consequently reversed, the lead lines are still not visible to the observer, as a switching function of the lead lines is prevented from taking place by means of the isolating layers.

An example of an insulating layer that may be employed is a developed photoresist layer, one surface of which is in contact with lead lines and on the opposing surface of which is deposited the field electrode and segment electrodes electrically connected to the lead lines through electrically conductive channels or vias the insulating layer.

The insulating layer is not restricted to a photoresists. It can be one of a large variety of insulator materials, SiO, MgO, or a polymeric film for example teflon, polyethylene, polystyrene, polypropylene or polycarbonate.

Another aspect of the invention involves a novel method for forming the lead lines, field electrode, and segment electrodes.

According to this aspect of the invention, there is provided a method of preparing an electrophoretic display device as hereinbefore described in which an electrically conductive coating such as indium oxide or tin oxide on an electrically non-conductive substrate such as glass is selectively etched to form the lead lines. The lead lines are then coated with a photosensitive layer such as Shipley AZ 1350J. This photosensitive layer is then selectively exposed with the aid of a photomask and the resultant exposed photoresist is then developed, leaving exposed channels or vias to the lead lines. A thin layer of an electrically conductive metal such as aluminium, or chromium is deposited on the photoresist for example by evaporation or electroless deposition or an electrically conductive metal oxide such as tin oxide or indium oxide by sputtering or by electroless deposition in such a manner that the walls of the vias or channels are completely plated thereby forming electrical paths between conductive layer and the lead lines. A second photosensitive layer is then deposited on the conductive layer, and is exposed according to a desired configuration and arrangement of the segment and field electrodes and then developed. The portions of the conductive layer under the exposed areas are then removed by etching and the resultant second photoresist is then removed leaving the segment electrodes and background or field electrodes arranged on the first photoresist layer and except through the vias, they are isolated from the lead lines by means of this photoresist layer.

Embodiments of the invention will now be described with reference to the ensuing specific examples and to the accompanying drawings in which:

*Figure 1* is a plan view of a substrate bearing electrode segment field electrode and lead lines for use in the electrophoretic display device of the invention.

*Figure 2* is a cross-sectional view of an electrophoretic display device of the invention taken through section A-A of Figure 1.

Referring to Figure 2 of the drawing, the

construction of a numeric display device of the invention is as follows:

A glass substrate 1 (approximately 2 x 3") coated on one surface with a thin transparent layer of indium oxide (for example Neastron glass manufactured by Pittsburgh Plate Glass Company) is cleaned and the indium oxide layer is coated with photosensitive layer of Shipley AZ 1350J on a spin coater at 2500 RPM and is prebaked at 45°C for 6 minutes. Using the appropriate mask for the lead lines the photosensitive layer is exposed to UV light for approximately 3 minutes.

After exposure, the resultant photoresist is developed in a Shipley developer for approximately 20 seconds, given a water rinse and baked at 120°C for 1 1/2 hours. The exposed portion of the indium oxide layer is then etched in hydrochloric acid at 45°C for approximately 1 1/2 minutes and then rinsed with water. A fill hole is then drilled into a corner of the glass substrate 1 using a diamond core drill. The remaining photoresist is then removed leaving the glass substrate 1 coated with indium oxide lead lines 2.

A photosensitive layer of Shipley AZ 1350J is applied over the lead lines 2 and substrate 1 and prebaked at 45°C for 6 minutes. The resulting photoresist layer 3 is then exposed to UV light for approximately 3 minutes using the appropriate mask for the vias, developed with Shipley developer and rinsed with distilled water, vias 4 or channels leading to lead lines 2 through photoresist 3 thus being formed. The substrate 1 is now baked for 1 hours at 120°C.

A layer of aluminium approximately 1000ÅA thick is evaporated on the photoresist 3. The resultant aluminium layer is coated with a photosensitive layer of Shipley AZ 1350J, prebaked at 45°C for 6 minutes and exposed to UV light for approximately 3 minutes using the appropriate masks for the numerical segments and field electrodes.

The resulting photoresist is developed in Shipley developer and rinsed with distilled water.

The exposed portions of the aluminium layer are etched in 16 parts of phosphoric acid, 2 parts of nitric acid, 2 parts of acetic acid and 1 part of $H_2O$, rinsed with $H_2O$ and blown dry with nitrogen. The remaining portion of the photoresist is exposed to UV light, developed off leaving exposed the numerical segment electrodes 5 and field electrode 6 formed from the aluminium layer. The substrate is then rinsed with distilled water and blown dry with nitrogen.

A syringe needle is sealed with epoxy to the fill hole, in the substrate 1. The substrate 1 is then sealed to the front electrode 7 consisting of a layer of indium oxide on a glass substrate 8, (2-1/4" × 3") while the latter is separated from glass substrate 1 by 2 mil Teflon shims. The word "Teflon" is a registered Trade Mark. The substrate 1 is then tacked with epoxy to the front electrode at four places along the periphery of the display. The epoxy is then cured, the Teflon shims are removed and the remainder of the periphery between the substrate 1 and the front electrode 7 is sealed with epoxy seal 9.

The resultant cell is filled through the syringe needle with an electrophoretic suspension 10 consisting of 15 cc of an approximately 7:3 r/r mixture of perchlorethylene: xylene with the specific gravity adjusted to 1.41, 420 mgs of diarylide yellow pigment, 40 mgs of Sudan Red - 4 BA dye and 210 mgs of FC-170-fluorinated alkyl polyoxyethylene ethanol (1%) or FC - 430 fluorinated alkyl esters (1% by wt.) commercially available from 3M as a charging agent for conferring a negative charge on the pigment and the needle is cut off and sealed with epoxy.

An application of −50 volts d.c. to segment electrode 11 in Figure 1 and +50 volts d.c. to the remaining segment and field electrodes with respect to the front transparent electrode 7 caused the negatively charged pigment in the area of negatively charged segment electrode 11 to be attracted to the more positive front transparent electrode 7 while the negatively charged pigment in the area of the positively charged remaining segment and field electrodes was attracted to those electrodes. This formed a bright yellow display in the shape of the segment electrode 11 against an opaque red background while no parts of the lead lines 2 were visible in the display. Upon reversal of the voltage polarities, by reversing switch 12 so that the segment electrode 11 was at +50 volts and the remaining segment and field electrodes were at −50 volts with respect to the front transparent electrode 7, the pigment in the area of segment electrode 11 was attracted to the now positive electrode and the pigment in the areas of the remaining segment and field electrode producing a display with the shape of segment electrode 11 as opaque red against a bright yellow background while no parts of the lead lines 2 were visible in the display.

An example of the use of the tone reversal mode of operation is in the operation of a digital clock using EPID cells for the display. A four digit clock has been constructed wherein the tone reversal is implemented once every second providing a "seconds" indicator for the clock.

WHAT WE CLAIM IS:-

1. An electrophoretic visual display device comprising: an electrophoretic suspension comprising an oqaque insulating liquid

containing charged pigment particles of a contrasting colour to that of said liquid and generally of a single polarity:

a first transparent electrode;

at least one segmented electrode and a field electrode having a major surface in opposition to the major surface of said first transparent electrode and spaced therefrom by at least one thin insulating member;

an insulating layer in contact with the surface of said segment and field electrodes and having electrically conductive channels or vias providing electrically conductive passages from said segmented and field electrodes through said insulating layer;

voltage supply means for supplying a reversible electric field between said first transparent electrodes and said segmented and field electrodes;

electrical lead lines positioned on the surface of said insulating layer remote from said segmented and field electrodes and electrically connected thereto through said electrically conductive channels or vias and with electricially conductive means electrically connecting said lead lines to said voltage supply means.

2. The electrophoretic visual display device of Claim 1 wherein the insulating layer is an inorganic dielectric material.

3. The electrophoretic visual display device of Claim 1 wherein the first transparent electrode is a thin coating of a transparent electrically conductive material on the surface of a transparent electrically insulating substrate.

4. The electrophoretic visual display device of Claim 1 wherein the segment and field electrodes are formed of a metal.

5. The electrophoretic visual display device of Claim 4 wherein the segment and field electrodes extend through said electrically conductive channels and form the electrically conductive paths through said channels.

6. The electrophoretic display device of Claim 1 wherein the insulating layer is a polymeric material.

7. A method of preparing an electrophoretic display device as claimed in Claim 1 in which an electrically conductive coating on an electrically non-conductive substrate has lead lines selectively etched therein, said lead lines being coated with a photosensitive layer selectively exposed to irradiation via a photomask and developed to give one or more channels or vias to the lead lines, depositing a layer of an electrically conductive material on the photoresist layer so that walls of the channels or vias form electrically conductive paths between the conductive layer and the lead lines, depositing a second photosensitive layer so that a desired configuration and arrangement of segment electrodes and field electrodes are formed after said layer is irradiated and developed, removing said exposed portions of the conductive layer by etching, and removing the second photosensitive layer to leave the segment electrodes and field electrodes arranged on the first photosensitive layer isolated from the lead lines by residual parts of the second photosensitive layer except through the channels or vias.

8. An electrophoretic display device substantially as hereinbefore described with reference to Figures 1 and 2 of the accompanying drawings.

9. A method of preparing an electrophoretic display device substantially as hereinbefore described with reference to Figures 1 and 2 of the accompanying drawings.

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1562653 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*

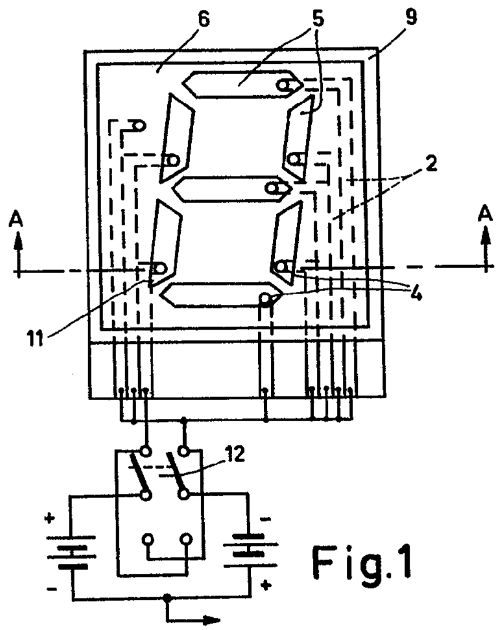


Fig.1

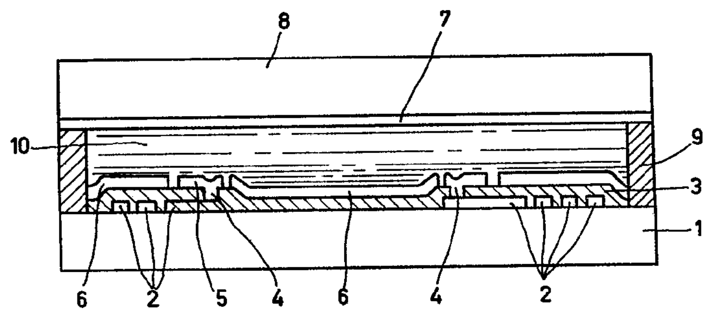


Fig.2